PB-230 679

GALVESTON BAY. WORK PLAN FOR THE DEVELOPMENT OF A COMPREHENSIVE WATER QUALITY MANAGEMENT PROGRAM

Dan M. Wells, et al

Texas Water Resources Research Program Committee

31 October 1966

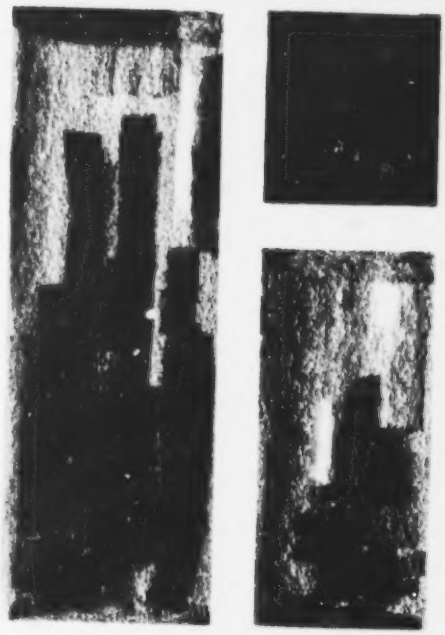
DISTRIBUTED BY:

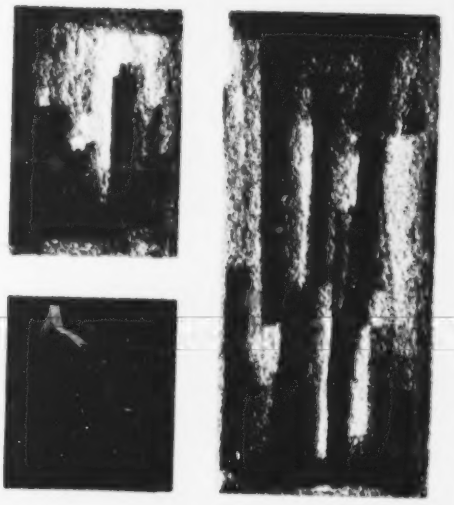
NTIS

National Technical Information Service
U. S. DEPARTMENT OF COMMERCE
5285 Port Royal Road, Springfield Va. 22151

PB 230 679

THE GALVESTON BAY WORK PLAN





PREPARED BY

TEXAS A&M UNIVERSITY

THE UNIVERSITY OF TEXAS

TEXAS TECHNOLOGICAL COLLEGE

Reproduced by
NATIONAL TECHNICAL INFORMATION SERVICE
U.S. Department of Commerce
Springfield VA 22151

WORK PLAN

For the Development of a Comprehensive Water Quality Management Program for Galveston Bay and Its Tributaries

Prepared

for

THE DEPARTMENT OF THE INTERIOR

Federal Water Pollution Control Administration
(Under Contract No. WA 66-1)

and

THE STATE OF TEXAS

Texas Water Pollution Control Board
(Under a grant from the Coordinating Board, Texas College and University System)

by

Dan M. Wells, Director
Water Resources Center
Texas Technological College
Project Coordinator

Ernest T. Smerdon, Director
Water Resources Institute
Texas A&M University

Earnest F. Gloyna, Director
Center for Research in
Water Resources
The University of Texas

Appendices included in this report were prepared by the following Committees:

BIOLOGY-ECOLOGY
J. G. Mackin, Chairman
Donald E. Wohlschlag, V.Ch.
E. Gus Fruh
B. J. Copeland
S. M. Ray
Edward Chinn

LAND-USE PLANNING
J. J. McGraw, Chairman
Hugo Leipziger-Pearce, V.Ch.

TRANSPORTATION
C. J. Keese, Chairman
C. V. Wootan

LEGAL
Corwin Johnson, Chairman

WATER QUALITY & POLLUTION CONTROL
W. W. Eckenfelder, Chairman
T. D. Reynolds, V.Ch.
R. W. Hann, Jr.
J. McCabe
C. Connell

RESOURCES
Stanley Arbingast, Chairman
J. Bradley, V.Ch.

OPTIMIZATION
E. F. Gloyna
E. T. Smerdon
Allen Kneese
D. M. Wells

RECREATION
L. M. Reid, Chairman
W. Kitchen, V.Ch.
Thomas Musiak
I. W. Schmedemann
C. D. Dowell

DISPERSION AND PHYSICAL MIXING
Frank Masch, Chairman
Walter L. Moore

CHEMISTRY
E. R. Ibert, Chairman
P. Parker, V.Ch.

HYDROLOGY
Keith Marmion, Chairman
G. Whetstone

WATER RESOURCES RESEARCH PROGRAM COMMITTEE

October 31, 1966

The Honorable Stewart L. Udall
Secretary of the Department of the Interior
Washington, D. C.

Attention: Mr. Frank Di Luzio
Assistant Secretary of the Interior
for Water Pollution Control

Mr. Joe G. Moore, Jr., Chairman
Texas Water Pollution Control Board
1100 West 49th Street
Austin, Texas

Attention: Mr. Hugh C. Yantis
Executive Secretary

Gentlemen:

We have the honor of submitting herewith a report, "Work Plan for the Development of a Comprehensive Water Quality Management Program for Galveston Bay and Its Tributaries," in fulfillment of contract number WA66-1. The work plan describes the overall requirement in terms of functional categories. Attention is directed to what should be done, how the work plan should be conducted, and when various phases of the plan should be initiated. The appendices describe detailed projects.

The development of a comprehensive Work Plan for studying the Galveston Bay System has led to several conclusions as to the scope of the proposed work and ways of undertaking the study. It has become clearer that a comprehensive study of this type involves many disciplines, ranging from economic and social considerations to engineering and physical science endeavors.

The consortium of State Universities which have joined together to assist the State of Texas in furthering its water resources management objectives is prepared to assist in the implementation of the plan.

Respectfully submitted:

Dan M. Wells

Dan M. Wells, Director
Water Resources Center
Texas Technological College
Project Coordinator

Ernest T. Smerdon

Ernest T. Smerdon, Director
Water Resources Institute
Texas A&M University

Earnest F. Gloyna

Earnest F. Gloyna, Director
Center for Research in
Water Resources
The University of Texas

cc: Coordinating Board, Texas College and University System

ACKNOWLEDGMENTS

The funds that made this work possible were provided by the United States Department of the Interior, Federal Water Pollution Control Administration, under terms of contract number WA66-1, and by the State of Texas through a grant from the Coordinating Board, Texas College and University System. The Texas Water Pollution Control Board provided invaluable assistance and support in all phases of the preparation of the plan.

Among the people to whom special appreciation is extended for their cooperation and assistance are the following:

Mr. Joe G. Moore, Jr., Executive Director, Texas Water Development Board

Mr. Hugh C. Yantis, Executive Secretary, Texas Water Pollution Control Board

Mr. Dave Smallhorst, Formerly Executive Secretary, Texas Water Pollution Control Board

Mr. George J. Putnicki, Federal Water Pollution Control Administration, Project Officer

Dr. Jack K. Williams, Commissioner of Higher Education, Coordinating Board, Texas College and University System

Mr. Jerome H. Svore, Regional Director, South Central Region, Federal Water Pollution Control Administration

Mr. Jerry T. Thornhill, Water Quality Specialist, Texas Water Development Board

General Robert M. Ives, President, Texas Air and Water Resources Foundation

Mr. Joe J. King, Executive Vice President, Texas Air and Water Resources Foundation

Mr. Sidney O. Brady, Chairman, Field Technical Survey Committee, Texas Air and Water Resources Foundation

Mr. Andrew Williams, Chairman, Water Source Committee, Texas Air and Water Resources Foundation

Many other individuals in many agencies of the state government, in the cities in the vicinity of Galveston Bay, in agencies of the federal government, in agencies of county governments, and in private businesses made invaluable contributions of time and information to the various committees working on this plan. The assistance provided by all of these people and agencies is appreciated and is hereby gratefully acknowledged.

SUMMARY

Galveston Bay is the largest, the most used, and the most productive bay on the Texas Gulf Coast. Continued municipal. industrial, and agricultural developments around Galveston Bay, as well as the diversion of fresh waters, will seriously affect the quality of the Bay waters and the regional development around the Bay unless remedial action is undertaken. To evaluate alternative measures for maintaining a suitable quality, it is necessary to immediately undertake a study project which has as its major objectives the determination of the functional relationships between incremental levels of water quality, the cost of achieving these levels, and the benefits that may be associated with each of the alternatives. To accomplish these objectives, certain basic studies must be made on the Bay system.

The total projects described herein have been divided into four separate, functional classes of work. The first class considers water quality. Work proposed includes the evaluation of the cost of achieving incremental levels of water quality under different types of management programs. The second functional class embraces the various social benefits that may be derived from alternative management plans. The third functional class of work embraces the effects of changing water quality on marine productivity. The fourth functional class of work involves the management program.

The estimated cost to conduct a highly coordinated and efficient study as described herein is $2,400,000, exclusive of the project manager's staff and organizational requirements, and of the money now being spent by various governmental agencies in studying the Bay. The magnitude of expenditures that will be required to substantially improve the present water quality of the Bay or to maintain the present quality under projected developments makes it imperative that this comprehensive study project be undertaken.

CONCLUSIONS AND RECOMMENDATIONS

It is recommended that a three-year project to study the impact of municipal, agricultural, and industrial developments on the Galveston Bay area and the effects of these developments on the water quality of Galveston Bay be initiated at the earliest possible date. This study is necessary to determine the fresh-water inflow needed to sustain a desirable aquatic environment; to evaluate the cost of achieving incremental levels of water quality; to determine the social benefits associated with incremental improvements in water quality; to determine the benefits to marine life associated with incremental improvements in water quality; and to determine the optimum management program for the Galveston Bay System.

The following specific conclusions and recommendations are made:

1. It is concluded that $2,400,000 will be required to support the technical phases of the project, exclusive of administrative funds required for the project manager's office, overhead charges, and funds normally alloted to the study of Galveston Bay.

It is recommended that the project manager, through his management organization, initiate study projects with public and private agencies that have demonstrated both competence and interest in specific aspects of the problem.

2. It is concluded that the "PERT" representation of the work plan as shown on a fold-out plate on page 11, represents a logical program of work.

It is recommended that consideration be given to the major aspects of the Galveston Bay Study Project, including the following:

A. Work Project Organization
B. Laboratory and Field Support Facilities
C. Instrumentation Development
D. Data Collection
E. Data Processing for Retrieval
F. Data Analysis and Analytical Model Development
G. Water Quality Protection (for Galveston Bay and tributaries)
H. Remedial Requirements for Water Quality Management
I. Alternatives for Water Quality Improvement
J. Recommendation on the Management of the Galveston Bay System, including fresh water requirements to sustain an acceptable quality.

3. It is concluded that standardized analytical and data reporting procedures must receive highest priority during the initial planning phases of the Project.

It is recommended that immediate attention be given to coordinating methods of reporting data, and to standardizing analytical tests, particularly as such reporting may pertain to test data requirements, punched cards, punched-paper tape, and magnetic tape.

4. It is concluded that separate technical and administrative reports will be required during the developmental, experimental, and evaluation phases of the Galveston Bay Study Project. Furthermore, it is concluded that a final evaluation report encompassing all of the information must be prepared.

It is recommended that these individual reports be written and documented as the various parts of the study are concluded. Interim reports for administrative review must also be presented as required under the management plan of the project manager and his advisory staff.

It is further recommended that a technical advisory group, initially established to provide guidance to the manager and his administrative staff, be charged with responsibility for the review of progress reports, interim evaluation reports, and special study reports.

It is recommended that the project manager and his administrative staff work out a suitable mechanism by which all cooperating and interested agencies be kept informed of findings and evaluations.

It is recommended that the manager and his administrative staff establish a very close liaison with other agencies and organizations which may be participating in or working separately on problems related to the Project. Duplication of effort is unwarranted and the responsibility for the elimination of duplication rests with the project manager and other agencies and organizations participating in the work.

5. It is concluded that immediate steps should be taken to establish an organization for the management of the studies defined herein.

It is recommended that immediate steps be undertaken to establish the extent to which the various state, federal, and local groups will participate in the study project so that their respective roles in the project management structure can be established. It is essential that local interests be included in the management structure at the policy-making level.

It is not appropriate to assume that an optimum level of water quality can be specified without regard to the type of program which legal and institutional factors make feasible. It is therefore recommended that a study of the legal aspects of a proposal to create a Galveston Bay Authority endowed with powers of enforcement of water quality standards, wastewater treatment, and water resource management be instituted immediately. Such an Authority or Board might be developed along the lines of the River Basin Development Boards that have been successfully used in Germany.

6. It is concluded that the organization established should consist of a project manager, an administrative staff, and a technical advisory group.

It is recommended that the project manager selected be a man with demonstrated managerial ability and that he be given authority to coordinate the project with all existing state, local, and federal agencies.

It is recommended that the project manager's staff consist of a specialist to direct water quality investigations, a specialist to direct investigations related to marine biology and fisheries, a specialist to direct studies in the field of economics, recreation, and land use planning, a specialist to direct studies related to the optimum use and development of bay resources, and personnel for budget control and contracting functions.

It is further recommended that the project manager and his staff be assisted by a consulting technical advisory group. This group would be composed of experts in the specialty areas receiving most attention in the study project.

7. It is concluded that the development of a detailed budget for the project manager, his immediate administrative staff, and technical advisory group is beyond the scope of this report.

It is recommended that the project manager have a sufficient staff to maintain complete control of the project. It appears that agencies providing funds for this management endeavor should provide a minimum of $175,000 per year for the duration of the project. These funds are in addition to the $2,400,000 recommended for the technical phases of the Galveston Bay Study Project.

8. It is concluded that it is unnecessary to list the competencies of all federal, state, and local public and private groups which might have an interest in undertaking certain aspects of the described work.

It is recommended that the project manager immediately solicit the cooperation and assistance of those agencies which have demonstrated competence and expressed interest in certain phases of the project. Included in this solicitation should be those local and state agencies which have capabilities either through their normal and routine operations or their technical staffs. For example, certain guidance might be derived from the local governmental and industrial groups with an interest in the Galveston Bay System. Another example might include the research and technical competence that exists in the various state universities of Texas. The roles of selected state and federal agencies specifically involved in water resource management have been defined by law and these need no further elaboration.

TABLE OF CONTENTS

Page

TITLE PAGE i

LETTER OF TRANSMITTAL ii

ACKNOWLEDGEMENTS iii

SUMMARY iv

CONCLUSIONS AND RECOMMENDATIONS v

TABLE OF CONTENTS vii

THE PROBLEM 1

- Need for Study 1
- Purpose of Work Plan 3
- Scope 3
- Organization for Development of the Plan 3

THE PLAN 3

- Relating Costs to Water Quality Improvements 4
  - Bay Quality Data 4
  - Effluent Data 4
  - Reaction Constants 6
  - Alternative Treatment Systems 6
  - Dispersion and Physical Mixing Data 6
  - Geophysical Data 6
  - Sediment Analysis 6
  - Evaporation and Interchange With Groundwater 6
- Relating Social Benefits to Water Quality Improvements 6
  - Economic Analysis 7
  - Recreational Benefits 7
  - Alternative Land Uses 7
- Relating Marine Productivity to Water Quality Improvement 8
  - Toxic Tolerance Testing 8
  - Phytoplankton Studies 8
  - Nursery Areas and Species Diversity 8
- Determining the Optimum Solution 8
  - Computer Model Development 8
  - Legal Studies 9

THE BUDGET 9

THE ORGANIZATION REQUIRED 10

THE SCHEDULE 11

THE PROBLEM

Texas has developed a comprehensive state water plan for the protection, conservation, development, redistribution, and administration of water resources to meet water needs for most purposes throughout most of the state through the year 2020 and beyond. The plan was designed for the optimum utilization of the state's water resources to meet projected needs for water for all purposes. Surface water, underground water, return flows, low quality water, and desalted brackish water were included in the studies of the total available supply. Elements of the state water plan were selectively phased to the year 2020 to serve municipal, industrial, irrigation, mining, hydroelectric power, navigation, and recreation needs as well as requirements for preservation of bays and estuaries.

The present municipal, industrial, and agricultural water requirements are known with a fair degree of accuracy and reasonable projections of requirements of water for these uses can be made, Fig. 1. About one-third of the water used for municipal and industrial purposes and possibly two-thirds of the water used for agricultural purposes is consumed. The portion that is not consumed is diminished in quality and ultimately returned to water courses. This return flow may be used for other purposes if it is of good quality or it may seriously impair the usefulness of the entire stream to potential down-stream users if it is of poor quality.

Under present conditions all water that is not used for municipal, industrial, agricultural, or other purposes may be said to be used for the preservation of bays and estuaries. The increasing future demands for water for other uses can be met only at the expense of the supply available for the preservation of bays and estuaries. At the same time the increasing quantities of return flows derived from increasing demands for water may seriously impair the usefulness of bays and estuaries for commercial and recreational activities unless the quality of the return flows is continuously upgraded.

With approximately 520 square miles of surface area, Galveston Bay is the largest and is generally thought to be the most important bay on the Texas coast, both economically and biologically. It has been reported to be the spawning and nursery grounds for 80 per cent of the total fishery products taken from the Gulf of Mexico along the entire Texas coast. It is widely used for water related recreational activities including boating, skiing, swimming, fishing and hunting. It is an important waterway for shipping interests, and the final stage of waste treatment for the heavy concentration of people and industry located in its vicinity. These multiple demands on the Bay are more often conflicting than compatible, and the Bay's value for each purpose is in some way related to the quality of the Bay and to the quantity of freshwater inflow to it.

NEED FOR STUDY

Conflicting demands for a limited supply of freshwater are increasing as are conflicting demands for use of the Bay waters. The development of a program for the sound future management of Galveston Bay and its tributaries requires a knowledge of the effect of water quality on each of the multiple demands made on the Bay as well as a knowledge of the effect of freshwater inflows on the Bay. With proper information available, decisions can be made to approximate optimum utilization of both freshwater and Bay water so that the maximum net benefit will accrue to the people of the area and region.

Much research has been done in the past on individual aspects of the problem, such as the relationship of marine animal production to the total freshwater inflow to the Bay. As a rule, such studies have dealt with only one or two variables and, while they have made valuable contributions to the body of knowledge that is available concerning the Bay, they have not been comprehensive enough to serve as a basis for conclusions. Thus, although general concepts are fairly well established, quantitative answers can be obtained only by means of a comprehensive and well-coordinated study that considers simultaneously the effects of all variables on the overall system.

The evaluation of benefits associated with incremental improvement in water quality requires evaluation of each of the separate benefits associated with improved water quality. Similarly, the evaluation of water for dilution purposes requires evaluation of several alternative means of achieving the same results. For example, any particular dissolved oxygen level can be maintained in a body of water that receives municipal and industrial wastes either by dilution of the wastes with a sufficient quantity of high quality freshwater or by subjecting all wastes to high levels of treatment. Treatment may be accomplished in either individual plants or by collection of all wastes and treatment in a central plant. Another alternative would be to collect all wastes and transport them by pipeline for disposal in the Gulf. For Galveston Bay, neither the cost of treatment by any of these alternatives or by any combination of these alternatives, nor the quantity of dilution water that would be required to maintain a given concentration of dissolved oxygen is known. Hence, no basis exists whereby treatment costs can be traded off against dilution water in order to find the optimum quantity of dilution water required for this specific purpose.

Numerous projects that would drastically alter the inflow, circulation, and interchange patterns existing in the Bay have been proposed. For example, the proposal to make the Trinity River navigable and the proposal to construct a hurricane barrier across the Bay would profoundly affect the quality of water in the Bay if constructed. Studies need to be made to evaluate both the benefits and detriments to Bay quality that might accompany the construction of such projects.

The salinity gradient that normally exists across the Bay is believed to be essential to the utilization of the Bay as a spawning and nursery area for marine animals. However, the incremental value of freshwater inflow as related to commercial fisheries products and to sports fishing and other recreational activities remains to be determined. Similarly, the feasibility of utilizing

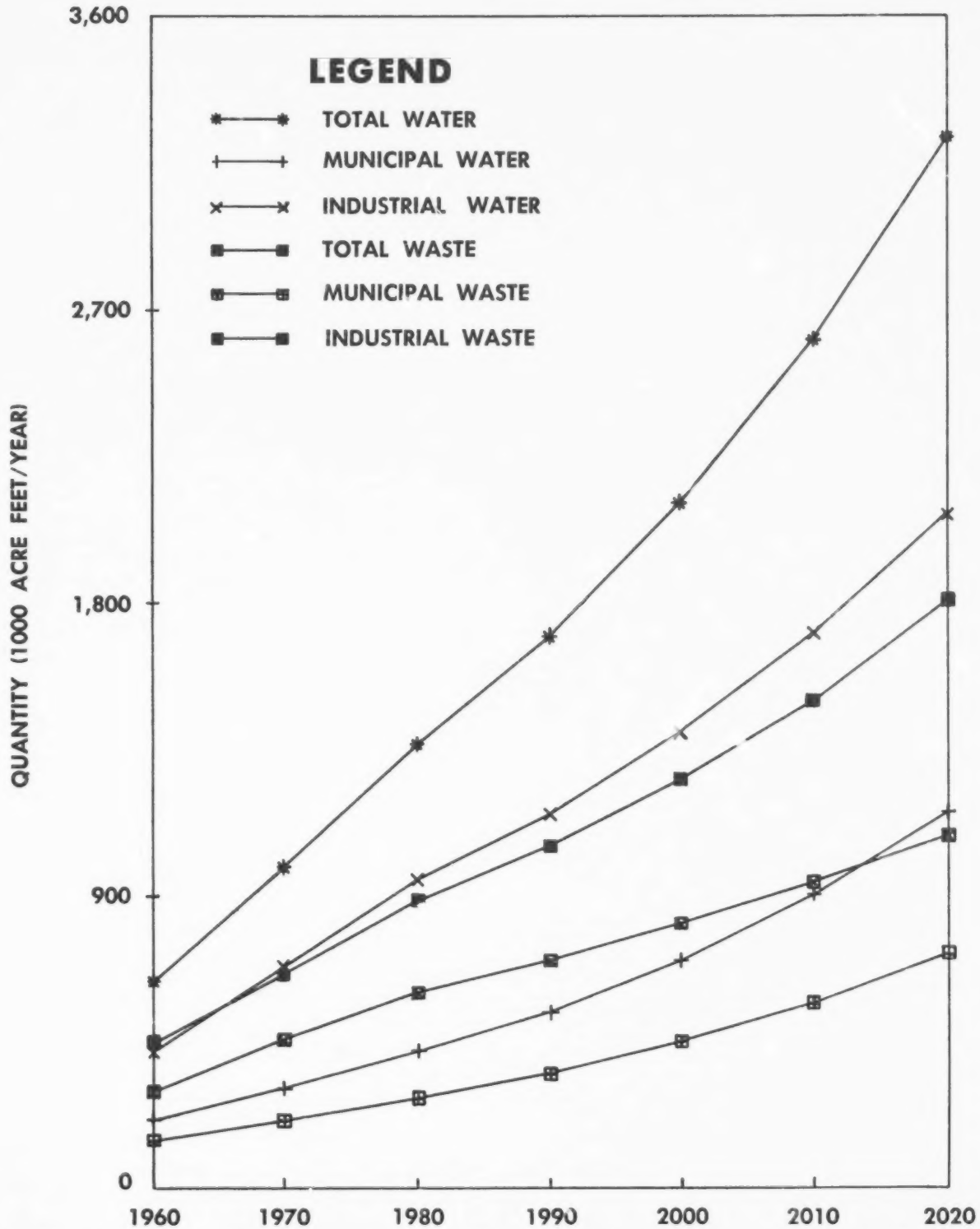


Fig. 1. Present and projected municipal and industrial water use and waste discharge for Galveston Bay area.

the same water for pollution control and for the maintenance of salinity gradients across the Bay needs to be explored. It is therefore apparent that the term "quality" as used herein includes a multitude of considerations, including dissolved oxygen levels, chemical quality, toxicity levels, temperature, salinity gradients, microbial concentrations, and many, many others.

The determination of the optimum quality of water in the Bay is very difficult because of the complexity of the physical, biological, and ecological systems involved. Intangible properties of the Bay such as aesthetic considerations are not amenable to complete economic evaluation and must be determined by value judgments and by surveys regarding public willingness to pay.

With the present state of knowledge of the interaction of forces on Galveston Bay, all decisions regarding its quality, and consequently the quantity of freshwater inflow needed, must be based on value judgments and best available estimates.

PURPOSE OF WORK PLAN

The purpose of the work plan is to define, organize, and schedule the work required so that the maximum benefits can be obtained from a given expenditure of time, money, and manpower. The best efforts of many disciplines will be required for the execution of the plan, and these efforts must be integrated into a coherent overall program in order to avoid duplication of effort and omission of essential details.

Of prime importance in the development of the work plan was the development of the PERT schedule which provides for studies to be completed in the quickest feasible time, and which provides for major findings of the study to be utilized as soon as they become available. Annual requirements for money and manpower have been programmed so that all work can proceed on a scheduled basis, thereby avoiding any uneconomical crash programs.

SCOPE

The work plan was designed to develop a comprehensive study of Galveston Bay and the surrounding area which in turn would provide the basis for a sound water quality management plan for Galveston Bay. Consideration has been given to all reasonable uses of the Bay and freshwaters in establishing study projects for determining the optimum quality for a variety of types of treatment programs. Items of work proposed involve a wide spectrum of disciplines ranging from the biological and physical sciences through the social sciences, economics, and law.

Mathematical models are proposed for several facets of the problem, and systems analysis techniques are prescribed to study certain aspects of the problem. The models and techniques thus developed will provide citizens and regulatory agencies with rational bases on which water quality management decisions can be made.

ORGANIZATION FOR THE DEVELOPMENT OF THE PLAN

The University of Texas, Texas A&M University, and Texas Technological College have recently joined together in a cooperative agreement for water resources research. The development of this plan is the first major joint undertaking of the institutions under the provisions of the agreement. As such, it offers proof of the viability of the agreement and of the schools' willingness and ability to work together. The University of Houston became a party to the agreement after this project was started, and it is expected to participate fully in any future joint efforts.

The plan was developed under the overall direction of the Water Resources Research Program Committee, consisting of the heads of the three institutions. The designees of this committee, the directors of the Water Resources Research Centers or Institutes at the respective schools, held several meetings at which plans were made for developing the plan. In the course of these meetings the total project was broken down into eleven specific study areas. From the best people available at the three institutions, a chairman and vice chairman were selected for each committee. Committee membership was then expanded to include other people who had a desire to make contributions to the plan. In order to get the widest possible range of viewpoints for each aspect of the problem, committee chairmen and vice chairmen were selected from different schools, and in some cases committee membership was made up of people from different disciplines. These arrangements proved to be beneficial in maintaining communications among the different schools, as well as between different committees.

THE PLAN

The work that must be performed to provide a reasonable basis for management decisions regarding the future quality of Galveston Bay waters is described herein. Each proposed work project was designed to yield specific information that is considered to be an essential input for management decisions. In general, the work outlined represents a concerted effort to solve the Galveston Bay water quality problem by the application of present knowledge and presently accepted concepts rather than by the development of new theories, concepts, or methodologies. The plan provides for acquisition of scientific and engineering data, but equally important, the plan considers the social structure of the Galveston Bay municipal and industrial complex. In those cases where present concepts are not sufficiently well-defined to form the basis of sound decisions it was considered essential that additional research be performed.

The overall plan, is presented in graphical form in THE SCHEDULE on page 11. It is suggested that THE SCHEDULE be folded out for reference in reading the following pages. This plan was synthesized from the detailed reports of the eleven committees which studied the problem and made recommendations for its solution. Reports prepared by each of the eleven committees which studied the problem are included as separate appendices. In most cases separate projects proposed by individual

committees are not recognizable herein because of rearrangements and combinations that have been made to avoid duplication of effort.

The diversity and range of problems to be studied in the proposed work projects make it essential that a competent and efficient management organization be established to supervise the execution of the plan. The work must be closely coordinated and tightly supervised if results obtained are to be of maximum value in the development of a comprehensive water quality management program for Galveston Bay.

The work proposed has been divided into four functional categories of projects. While none of these categories has distinct boundaries, they provide convenient frames of reference within which to discuss the overall plan and on which to base the management organization for execution of the plan. The first functional category of work is concerned with the evaluation of the cost of making incremental improvements in water quality for both present and future conditions and for a variety of different treatment programs. The second functional category is concerned with evaluation of the social benefits associated with incremental improvements in water quality, while the third functional category is concerned with evaluating the benefits to marine life associated with incremental improvements in water quality. The fourth category uses results obtained in the first three along with legal research and mathematical modeling techniques to determine the optimum feasible water quality management program for Galveston Bay and its tributaries.

RELATING COSTS TO WATER QUALITY IMPROVEMENTS

It is probably true that any desired quality level in Galveston Bay could be attained within a few years by the simple expedient of requiring all waste dischargers to upgrade their effluents to some arbitrary level of quality, measuring the resulting water quality throughout the Bay, further upgrading effluent standards, again monitoring the results obtained, and continuing this cycle until the desired level of quality had been obtained. Once the desired quality level had been obtained it could be maintained by continuously upgrading effluent standards as the quantity of waste discharges increased. The disadvantages of this system of arbitrary standards are that no rational basis exists for establishing desirable water quality objectives and that a much less expensive method for attaining any desired level of water quality can undoubtedly be found. The objective of work outlined herein is to find the optimum means of meeting any desired water quality criteria for any desired treatment system. The specific work projects outlined below must be executed to fulfill this objective.

Bay Quality Data

The collection, analysis, and processing for high speed retrieval of water quality data for Galveston Bay are essential to the basic objectives of the plan. Detailed and accurate information is needed to evaluate the key parameters in the system, to determine the total contribution of each source of pollutant to the Bay, and to determine the fate of pollutants derived from each source under various climatic conditions.

Two methods will be used to collect water quality data from the Bay. First, a series of automatic, continuous sampling stations will be installed at key stations within the Bay to continuously monitor and record pH, dissolved oxygen concentration, and conductivity. These stations must also be capable of either continuously monitoring and recording such key parameters as COD and phosphorus, or of taking samples on a periodic basis and preserving them for later laboratory analysis. Development of the instrumentation required for these continuous monitoring stations will be the first and one of the most important duties of the task force engaged in the collection and analysis of data. The automatic stations will be utilized for the entire three-year study period, and some of them can be moved to new locations in the Bay at intervals of six to eight months in order to gain a clear understanding of the functioning of the entire Bay system. These sampling stations will be located initially at the points indicated in Fig. 2. An analysis of existing data plus the analysis of additional data that will be collected by conventional means during the course of the survey will indicate where the stations should be moved after the initial six to eight month runs have been made. Data collected will be of very little value unless it is processed and stored on either punched tape, punched cards, or magnetic tape so that electronic computers can be used for its analysis.

Additional water quality data will be collected in the Bay by more conventional sampling techniques using boats. One or more boats and crews will be utilized to collect samples from selected locations throughout the Bay on a routine, periodic basis. The precise location of sampling stations and the sampling schedule should be determined by the technical staff and the technical advisory group. It is essential that standardized analytical tests and reporting methods be used by all laboratories with which arrangements for analysis are made.

The entire data collection, analysis, and reporting procedures must be critically reviewed periodically throughout the study by the technical staff and the technical advisory group to make certain that all data collected are both useful and usable.

Effluent Data

Field surveys of municipal and industrial discharges as well as urban, rural, and agricultural drainage will be performed by mobile laboratories provided for the purpose. About sixty major industrial plants and twenty-five major municipal plans will be surveyed for a minimum of five or six days each during the first year. During the second year such other major industrial plants as deemed appropriate will be surveyed for five or six days each, and a larger number of smaller industrial plants and municipal plants will be surveyed for two or three days each. These surveys will measure both quality and quantity of effluents, thereby making it possible to estimate with a fair degree of accuracy the total contribution from both municipal and industrial plants to the Bay. The characteristics of urban and rural run-off will be determined by surveys made by the mobile laboratories on selected water courses following rains at two or three different times of the year. The characteristics of agricultural return flows, primarily return flows from rice irrigation, will be determined by

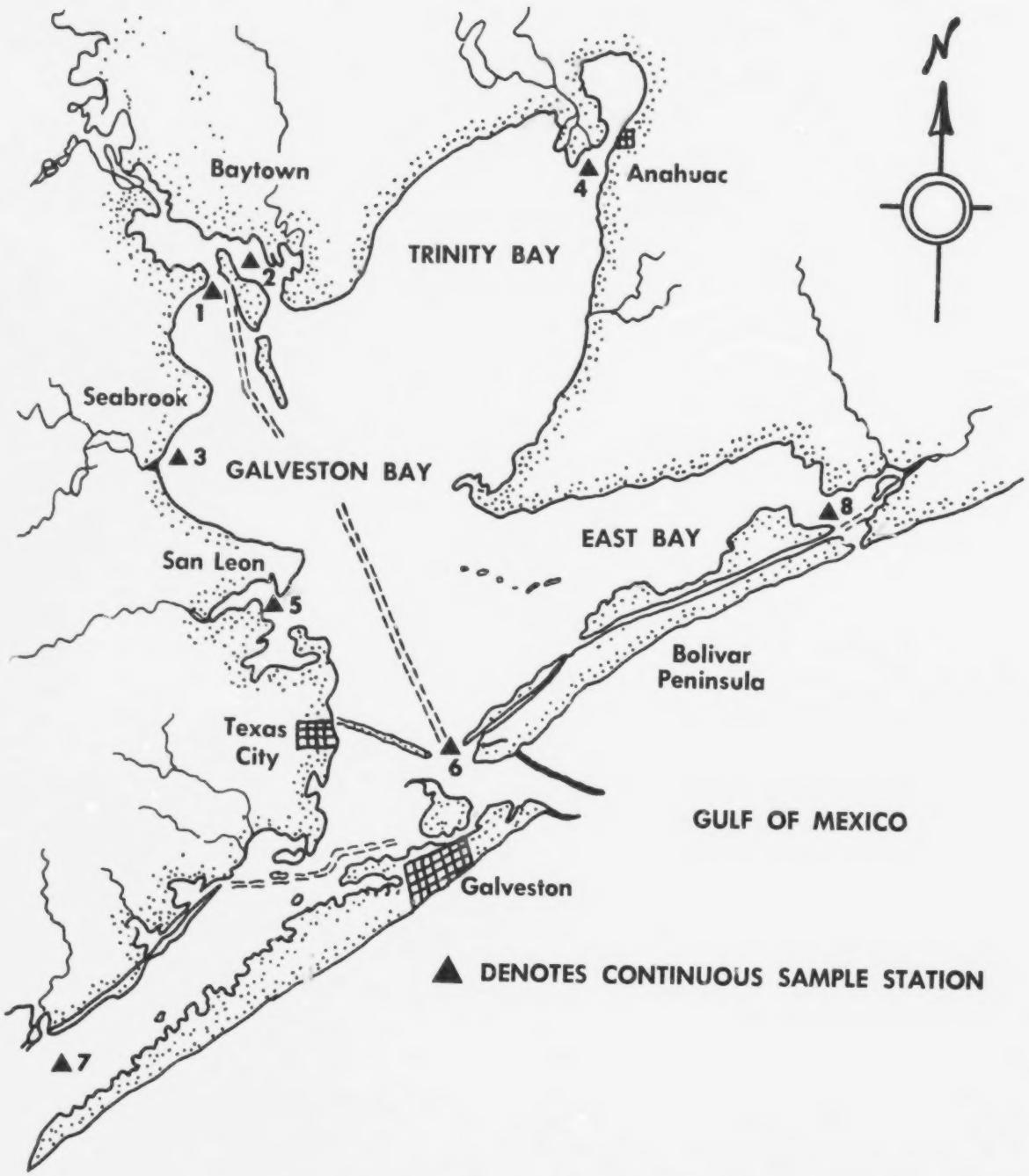


Fig. 2. Location of sampling stations in Galveston Bay.

detailed analysis of return flows from selected areas when the irrigation water is released from rice fields.

The pollutional load added to the Bay by ships navigating its waters will be determined. Discharges of sanitary sewage from such ships can be evaluated in terms of the complement of men aboard. Industrial type wastes resulting from pumping of bilges and accidental spills must be evaluated on the basis of the type of cargo carried.

Future waste loadings that may be discharged to the Bay will be determined as a function of future economic development of the Bay area. Completion of the field surveys and required laboratory analyses will make it possible to develop curves relating waste production to plant output for each of several types of industries located in the Bay area.

Reaction Constants

The assimilative capacity of the Bay is heavily dependent upon the rate at which pollutants are degraded by biota in the water. Relatively small quantities of easily degradable material may cause severe local problems that dispersion and physical mixing of the pollutant would prevent in the case of less readily degradable material. The rates at which organic pollutants in municipal wastewaters are degraded by microbial action are reasonably well known. This is not the case with pollutants in industrial wastewaters. The rate at which industrial wastes are broken down depends not only on the product manufactured but also on the raw material used and on the manufacturing process involved. Because of the profound effect which degradation rates may have on the capacity of a body of water to assimilate wastes without serious adverse effects, it is necessary to evaluate the reaction rates for many different types of industrial wastes, both individually and in combination with various other types of wastes. Laboratory studies performed on samples collected by the mobile laboratory crews and utilizing well established techniques will be used for evaluating these rates.

Alternative Treatment Systems

Alternate methods of collecting, treating, and disposal of municipal and industrial wastes in the area must be identified and evaluated in order to find the optimum system for achieving any desired water quality levels. Engineering investigations must be made to determine the feasibility of attaining various quality levels by treatment in individual plants, collection and treatment in one or more larger plants, in-channel treatment by aeration or other unconventional means, segregation of wastes for selective treatment and reuse, collection and disposal of wastes by piping to the Gulf, and various combinations of all the above methods. These investigations will have to be made in sufficient detail to permit credible cost estimates to be made.

Dispersion and Physical Mixing

Dispersion and physical mixing of pollutants with the contents of the Bay play a major role in determining its assimilative capacity. Detailed wind, wave, current, hydrologic, temperature, physiographic, and tidal data must be collected both from the Bay and from models of the Bay to evaluate the effects of these factors, to develop reasonable physical mixing models, and to evaluate the effect of possible changes in the physiographic features of the Bay, such as the addition of hurricane barriers or other major construction. The feasibility of improving the Bay's assimilative capacity by making physiographic changes to improve mixing will be investigated.

Geophysical Data

The effects of alterations to watershed characteristics as a result of continuing urbanization and industrialization must be investigated. Changes in quality and quantity of runoff resulting from urbanization of the area will be evaluated.

Sediment Analysis

Much can be learned about the recent history of sources of pollutants that have been added to the Bay by the analysis of sediment cores for changes in concentrations of ^{14}Carbon and ^{3}Hydrogen with time. The sediment analysis proposed will give an indication of the origin of pollutants (whether municipal or industrial) and of the currents that have caused the existing distribution of such pollutants throughout the Bay.

Evaporation and Interchange with Groundwater

The salinity of the Bay is influenced by both interchange between the Bay and adjacent freshwater aquifers and by evaporation from the Bay. Evaluations of evaporation rates and of the interchange rate between the Bay and adjacent aquifers are therefore necessary both from the standpoint of maintaining Bay quality and from the standpoint of avoiding contamination of the adjacent aquifer. A study of well quality changes with time and with drawdown will indicate the extent to which interchange occurs. Consideration must also be given to natural variations in the quantity of freshwater inflow, and to the changes in quantity of freshwater inflow which will accompany future interbasin diversions to and from the Trinity and San Jacinto River Basins.

RELATING SOCIAL BENEFITS TO WATER QUALITY IMPROVEMENTS

It can be stated unequivocally that society derives benefits from improvements in water quality. The benefits may be in the form of increased opportunities for recreational use of the water, improvements in health, increased property values resulting from the natural beauty of clean water, increased economic growth, and many other tangible and intangible factors. Thus, if improvements in water quality could be made at no cost, a well-informed citizenry would surely demand that the quality of water in the Bay be maintained at a very high level. Since improvements in water quality can be made only by the expenditure of substantial sums of money, it is apparent that some quality level exists at which the further expenditure of money for quality improvements will not yield a reasonable return in the form of benefits. The purpose of the work proposed herein is to quantify the functional relationship between water quality and social benefits so that the optimum quality level can be approximated. The following specific work projects must be executed to fulfill this purpose.

Economic Analysis

Water quality problems that exist in the Galveston Bay area are a direct result of the economic development that has occurred in the area. It is therefore essential that the economic and social factors affecting pollution be identified and evaluated.

A review and analysis of existing economic data will be made, and existing data will be updated to reflect present conditions. Factors which will be considered include the present population and population characteristics, mineral, agricultural, forest, marine, and water resources, the outlook for present and possible future manufacturing industries in the area, and the growth prospects for such service industries as finance, retail, wholesale, government, and transportation.

Preliminary population and economic projections based on currently available data will be made as early as possible in the study. These preliminary projections are needed by others participating in the work.

Preliminary economic projections will be refined and coordinated with other factors such as land use, recreation, and transportation facilities projections to make final economic and population projections.

Recreational Benefits

Recreational benefits associated with improved water quality in Galveston Bay may prove to be a decisive factor in the final establishment of water quality objectives for the Bay. The large area of protected Bay water is ideally suited to boating, sailing, water skiing, and other water-related sports, as well as to sports-fishing and hunting. The increasing amounts of leisure time available, when coupled with the increasing affluence of the average citizen, will undoubtedly result in a recreational demand growth rate far in excess of the population growth rate.

The opportunity for water-associated recreation results from the availability of a body of water having stipulated characteristics at a specific location. The easy accessibility of Galveston Bay to the large concentration of people in the Houston-Galveston area gives it an enormous potential for recreational use provided the quality of the water in the Bay does not inhibit such use.

The first step in evaluating recreational benefits associated with incremental improvements in water quality is the inventory of recreational sites in Galveston Bay and its subdivisions and in the nearby coastal areas. Data to be obtained will include the supply of existing water-associated recreation sites, resource ownership, and available access for water-related recreation. Factors to be considered include the steepness and elevation of banks, the composition of banks and degree of erosion, the depth of water near the shore, and the access of contiguous land areas to public highways. The availability of existing and potential physical resources that may be utilized for recreational purposes will be a prime factor in the determination of future benefits associated with improvements in water quality.

Present recreational use levels in the Bay will be determined and projections of demand by recreational activity will be made. Participation coefficients for individual water-associated activities will be evaluated, and an analysis of relationships involved in various activity-water quality combinations will be made. As a result of these analyses it is anticipated that it will be possible to quantify the functional relationship between water quality and recreational benefits with a reasonable degree of accuracy.

Alternative Land Uses

Land-use patterns that develop in the Bay area—the concentration of people and industry in specific areas, the type of industrial development that occurs, and the development of transportation, communications, shopping and governmental facilities—affect the quality of the Bay water and are, in turn affected by Bay water quality. The development of a water quality management program for Galveston Bay and its tributaries therefore requires that consideration be given to some of the alternative land-use patterns that may develop in the future. It is not the purpose of the work proposed herein to develop a comprehensive land-use plan for the Galveston Bay area. Rather, it is proposed that several preliminary alternative land-use plans for the area be developed so that the impact of various levels of Galveston Bay water quality on each of the alternative plans can be evaluated.

The preparation of alternative general plans for the development of the area requires a knowledge of existing land uses. An inventory of property ownership, land use, population distribution, resources, communication and transportation facilities, public utilities, community facilities and services, physical features of the area, and other currently existing plans must therefore be made. The participation of public officials, citizens, and other interested groups throughout the region is essential and will be encouraged.

Preliminary general plans will then be drawn to include proposals for residential, commercial, industrial, recreational, agricultural and public land uses, and circulation and transportation features. Major community facilities will also be delineated. A report accompanying each alternate general plan will contain a description of the plan and will include statements of the assumptions, objectives, principles, and standards underlying the planning features. Methods for implementation of each alternate plan will also be included.

The evaluation of alternate plans developed will be a very complex process. Each alternate plan's effects on the water resource system and ecology of the area will be estimated.

The extent to which people value unpolluted waters, natural beauty, and the type of environment which will be created by each alternative plan will be evaluated. It will also be necessary to estimate the costs of providing public facilities such as transportation, utilities, governmental structures, public education, and recreational facilities under each alternative plan, and to estimate the impact of each plan on future industrial development and population growth in the Galveston Bay area and in the state as a whole.

The work proposed herein must be closely coordinated with that proposed in each of the other portions of the overall plan if the objectives for which the project

was undertaken are to be met. Progress must be reviewed periodically and indicated changes must be made in procedures, approaches, and objectives where appropriate. So complex a problem can be solved only by a rational approach that is continuously refined and improved as progress is made.

RELATING MARINE PRODUCTIVITY TO WATER QUALITY IMPROVEMENT

The productivity of Galveston Bay and the favorable environment which it provides for spawning and nursery purposes are the foundations on which much of the commercial fishing industry along the entire Texas coast is based. It therefore follows that the commercial fishing industry along the coast would be seriously damaged if the quality of Galveston Bay should deteriorate to such an extent that it is no longer usable as a spawning and nursery area for marine animals. The value of the Bay and adjacent waters for sports fishing would be similarly affected. Thus, in a negative way it is possible to say that if the quality of the water in Galveston Bay were sufficiently poor, the Bay would have no value to the sports and commercial fishing industries. With the present state of knowledge, however, it is not possible to determine the value of benefits to marine life associated with any incremental improvements in water quality. The work outlined herein is designed to provide a reasonable basis for estimating the benefits associated with such incremental improvements in water quality.

Toxic Tolerance Testing

It is proposed to make toxicity and toxic tolerance tests for shrimp, crabs, oysters, and certain varieties of finfish under a variety of environmental conditions. The response of these animals to different concentrations of toxic materials under varying conditions of freshwater inflow, temperature, salinity, and dissolved oxygen concentrations will be determined. The proposed tests will reveal the short-term effects of rapid changes in these variables resulting from seasonal variations of inflow and temperature and from rapid changes in the quantities of wastes discharged. Estimates of long-term effects of gradual changes in water quality on the biological system in the Bay can be obtained from a thorough analysis of existing data. A reasonably adequate indication of the total effect of changes in toxicity levels on the productivity of commercially important animals in the Bay will be obtained by combining the long-term effects of gradual changes with the short-term effects of seasonal and other rapid changes to be evaluated herein.

Phytoplankton Studies

Phytoplankton studies proposed are designed to measure the photosynthetic activity in the Bay at different seasons of the year under different conditions of freshwater inflow and water temperature, and with varying concentrations of nutrients present. The purpose of these studies is to determine the concentration of plant nutrients that will result in excessive plant growth in the Bay. Two approaches to the problem are proposed. One will utilize ^{14}Carbon uptake as a measure of photosynthetic activity, and the other will utilize nutrient enrichment studies to determine limiting nutrient concentrations. The two approaches are considered to be necessary because neither one has been applied to a bay or estuary before. Thus each method will serve as a check on the accuracy of the other, and the two methods should provide reasonable answers to the problem.

Nursery Areas and Species Diversity

The importance of shallow water nursery areas in Galveston Bay to the commercial and sports fishing industries makes it necessary to determine the location and nature of these areas and to assess their varying environmental characteristics and usage, especially for oysters, shrimp, crabs, and fishes. The usage of certain areas for nursery grounds will be determined by sampling the areas with nets and trawls to collect the animals at all stages of development. Corresponding measurements of salinity, temperature, dissolved oxygen, and dissolved and suspended organic matter will be made to relate these parameters to the degree of usage of the areas by important species of marine animals. Species diversity studies, which give good indications of the overall condition of the water, will be made by utilizing the data collected in evaluating nursery and spawning grounds. The preservation of these nursery areas will undoubtedly be one of the prime biological benefits associated with improved water quality in Galveston Bay.

DETERMINING THE OPTIMUM SOLUTION

The work thus far outlined is expected to yield the basic data required for making the benefit-cost analyses that will indicate the optimum quality levels for Galveston Bay under a variety of proposed management systems. The voluminous quantities of data that will be generated, and the complexity of the interrelationships between different elements of the overall system, will make the required analyses of benefit-cost relationships very exacting and difficult. Mathematical models programmed for solution by electronic computers must be developed for several facets of the overall system. All such models developed must be written in compatible units so that a large number of possible solutions can be found automatically and rapidly by electronic computer. Thus, the system must be designed with capability for analyzing not only the benefits associated with a wide range of water quality objectives, but also the costs of achieving all levels of water quality under different systems of waste management. It is not appropriate to assume that an optimum level of water quality can be specified without regard to the type of program which legal and institutional factors make feasible.

Computer Model Development

It is proposed that all computer models, including the physical mixing model, the water quality model, the biological model, and such other models as are deemed necessary, be developed by a separate group organized for the purpose. It is imperative that those responsible for developing these models take a part in the planning of all work projects so the information and techniques developed will be in a form that is suitable for use in the computer models, and so the models developed will utilize all available data. They must also participate in periodic reviews of work as it progresses and be prepared to recommend changes in procedures and objectives as appropriate.

Legal Studies

The implementation of any plan for the management of Galveston Bay will undoubtedly involve the removal of numerous legal obstacles. The nature of legal obstacles that may need to be removed will depend on the alternative methods that are considered for management of the Bay. At this time, it is not possible to anticipate all problems that may develop in the selection of the management system. It is therefore proposed that initial legal investigations be confined to those problems which are certain to arise, and that subsequent legal investigations be confined to those problems which actually do arise in the course of execution of the plan.

Work should be instigated immediately on the general problem of developing a governmental framework for the planning and control of land use compatible with optimum utilization of the waters of Galveston Bay, because this alternative obviously must be considered. It is also appropriate to immediately institute a study of the legal aspects of a proposal to create a Galveston Bay Authority endowed with powers of enforcement of water quality standards, wastewater treatment, and water resource management.

There is no legal assurance that any freshwater inflow determined to be optimum for the management of Galveston Bay water quality will be available for use in the Bay. Legal research therefore should be undertaken to determine the measure of the limitation imposed upon such inflow by existing water rights on the sources of such flow.

As the study progresses, careful consideration must be given to the legal aspects of any management proposals that are considered. Only by such consideration and, where necessary, legal research, can infeasible or illegal solutions be eliminated from consideration.

THE BUDGET

Successful execution on the plan will depend on timely provision of necessary financial support. The estimates presented below are based on the assumption of little or no overhead expense. It is assumed that regulatory agencies will continue their normal levels of expenditure in the area, but perhaps the work effort can be coordinated more effectively. The following annual monetary requirements are anticipated:

	Budget Item		1st Year	2nd Year	3rd Year
1.	Data Collection and Water Quality Analysis		$ 350,000	$ 250,000	$195,000
2.	Effluent Data		90,000	60,000	—
3.	Evaluate Reaction Constants		45,000	40,000	—
4.	Evaluate Alternate Waste Collection, Treatment, and Disposal Systems		—	50,000	30,000
5.	Dispersion and Physical Mixing Analyses		80,000	60,000	60,000
6.	Climotological and Geophysical Data Collection and Analysis		20,000	20,000	—
7.	Bay Sediment Analysis		25,000	15,000	—
8.	Evaporation Studies and Hydrologic Studies of Bay and Adjacent Aquifers		20,000	30,000	—
9.	Economic Analysis		70,000	50,000	30,000
10.	Recreational Benefits		25,000	45,000	10,000
11.	Alternative Land Uses		50,000	90,000	10,000
12.	Toxic Tolerance Testing		90,000	80,000	30,000
13.	Phytoplankton Studies		10,000	15,000	—
14.	Shallow Water Nursery Areas and Species Diversity Studies		10,000	15,000	—
15.	Computer Model Development		40,000	80,000	130,000
16.	Legal Studies		20,000	20,000	40,000
	Subtotal for Technical Phases		$ 945,000	$ 920,000	$535,000
	Subtotal for 3 years	$2,400,000			
	Estimated Management Budget		175,000	175,000	175,000
	Total Project Budget		$1,120,000	$1,095,000	$710,000

The work proposed in budget items 1 through 16 is explained in order in THE PLAN. Timing of individual projects is indicated in THE SCHEDULE.

This budget does not provide for the establishment of a separate laboratory. Existing laboratories should be used on a cooperative or contractual basis. The budget is arranged in accordance with anticipated costs for work in various problem categories. The work may be accomplished more effectively in some cases by contractural arrangements and in other cases by technical staffs assembled under the aegis of the agency responsible for the study.

THE ORGANIZATION REQUIRED

This plan offers a unique opportunity for interested federal, state, and local agencies to participate cooperatively in the development of a comprehensive water quality management program for a major water resource on the basis of a rational and objective analysis of the beneficial and detrimental effects of all levels of water quality on the surrounding area. This cooperative approach to a multi-disciplinary problem will make its management a very exacting responsibility. The extremely high degree of coordination that will be required for all portions of the study makes it absolutely necessary that a project manager and a management staff of the highest caliber be selected and that the managerial team selected be given complete responsibility for excution of the plan.

It is not appropriate to prepare a detailed organizational chart for execution of the plan at this time, both because this should be the projects manager's prerogative and because it is not now possible to determine the degree to which various levels of private and governmental agencies will participate in the execution of the plan. Hence, only broad outlines of the organization can be indicated.

Fig. 3 indicates in a general way the form the organizational structure should take. The policy-making group indicated should be composed of representa-

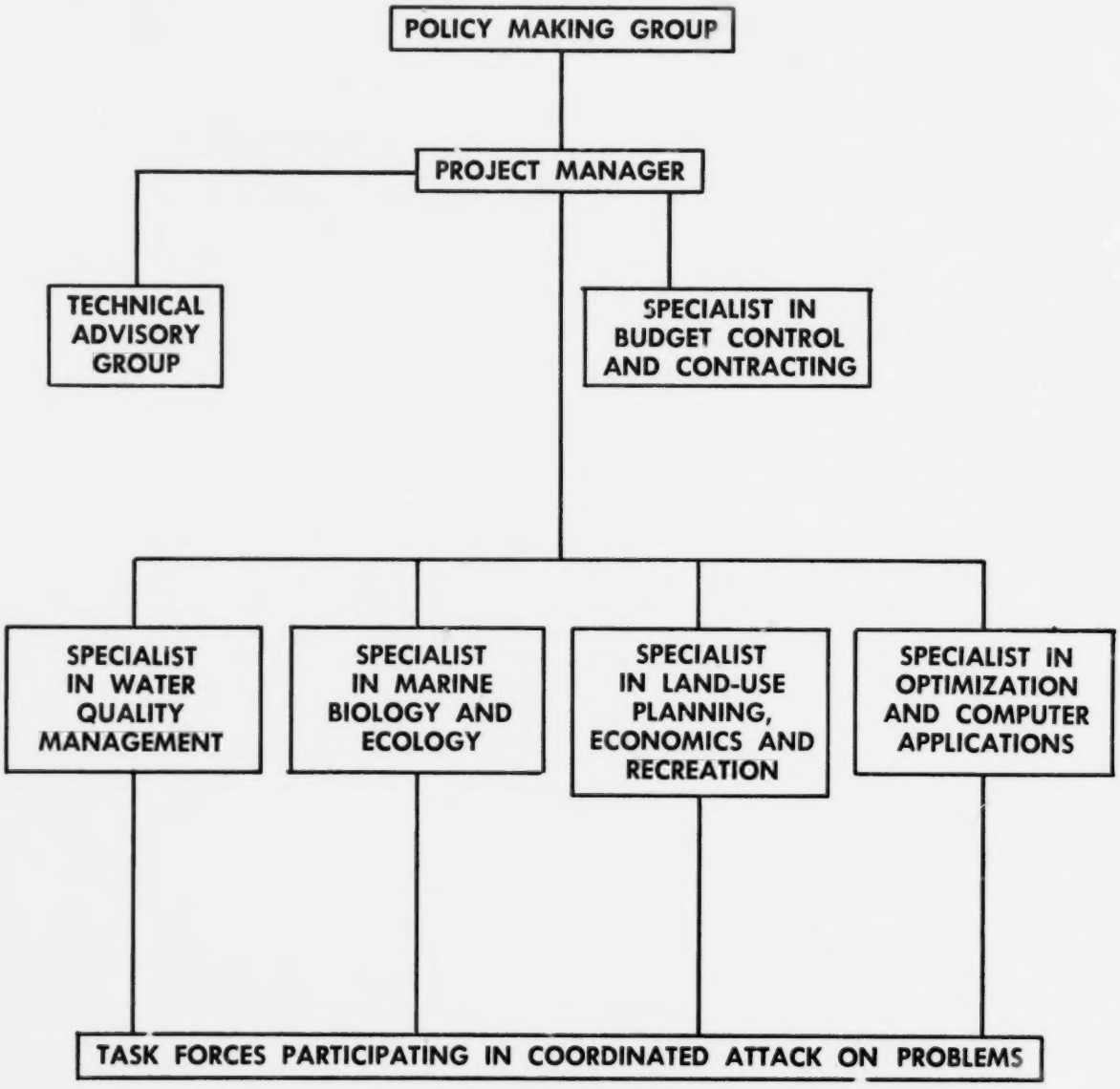

POLICY MAKING GROUP
PROJECT MANAGER
TECHNICAL ADVISORY GROUP
SPECIALIST IN BUDGET CONTROL AND CONTRACTING
SPECIALIST IN WATER QUALITY MANAGEMENT
SPECIALIST IN MARINE BIOLOGY AND ECOLOGY
SPECIALIST IN LAND-USE PLANNING, ECONOMICS AND RECREATION
SPECIALIST IN OPTIMIZATION AND COMPUTER APPLICATIONS
TASK FORCES PARTICIPATING IN COORDINATED ATTACK ON PROBLEMS

Fig. 3. Outline organizational chart for executing the work plan.

tives of all agencies which are vitally interested in water quality and which make substantial contributions to the execution of the plan. This group should establish policy for the work and assist the project manager in securing the necessary degree of cooperation and support from the various agencies which will be involved in the project.

The project manager must be a man who is both knowledgeable in the broad field of water resources and of demonstrated managerial skill. The manager's staff should consist of a specialist in the field of water quality investigations, a specialist in the field of marine biology, a specialist in the field of land-use planning, a specialist in the field of optimization and economics, and the necessary personnel for budget control and contracting operations. It appears that these technical specialists should play dual roles as members of the project manager's staff and as supervisors of the task forces that will be engaged in executing the plan, although the final decision in this respect should be left to the discretion of the project manager.

The project manager and his staff should be assisted by a consulting technical advisory group. This advisory group should be composed of experts in the specialty areas receiving most attention in the study project. The function of this group should be to assist in the establishment of means and objectives for the technical phases of the study, to assist in the development of standardized data collection analysis and reporting procedures, to review periodically the progress of the work, and to review reports submitted by the various task forces as the project progresses.

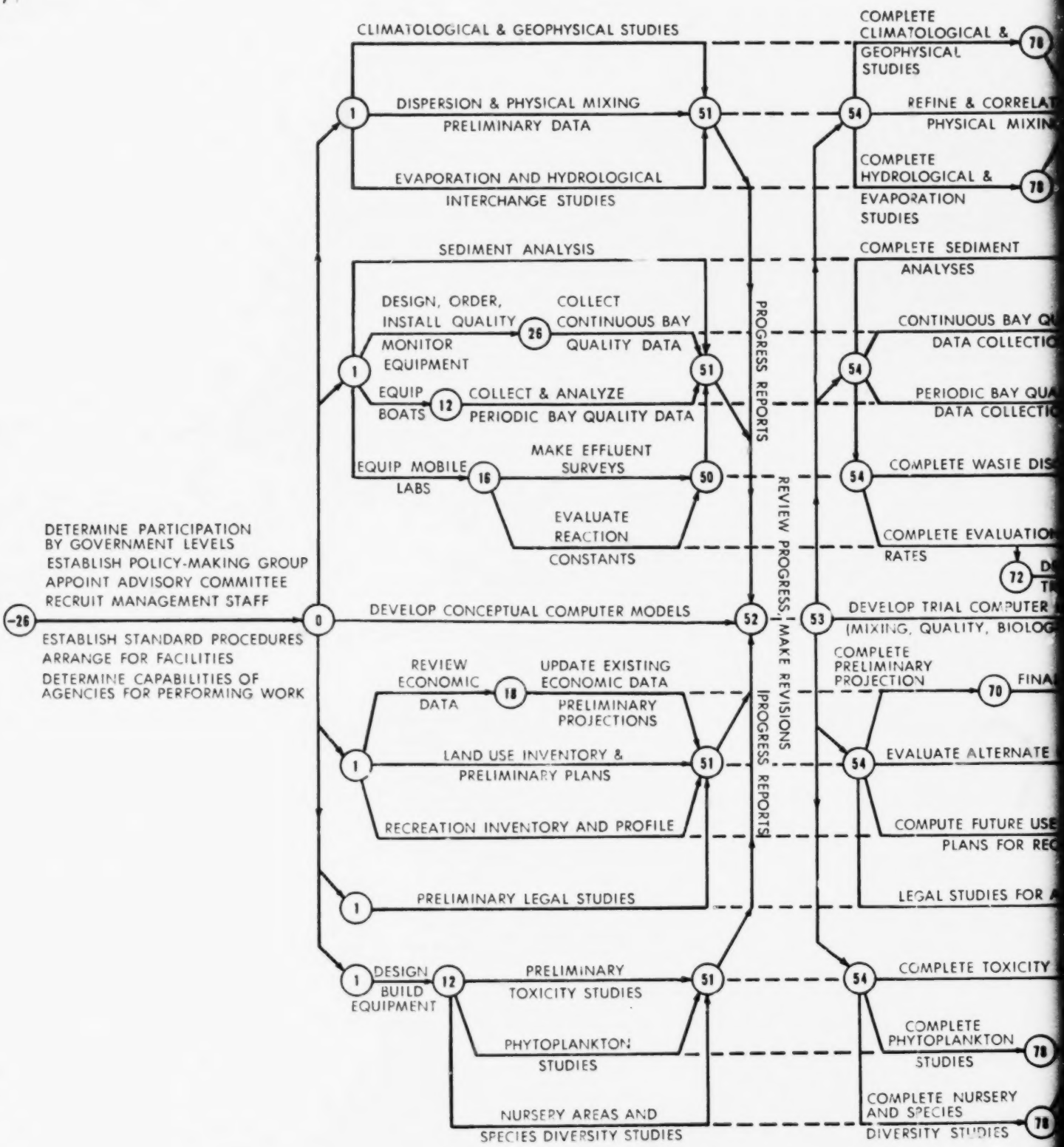
The organization of specific task forces must be left to the discretion of the project manager and his staff so that cognizance can be taken of the conditions that exist at the time the project is started.

THE SCHEDULE

The work to be performed is presented in graphic form in THE SCHEDULE on the following page. All work has been scheduled to start at the earliest possible time consistent with the availability of data, and to be completed in the shortest practicable time. Periodic reviews of the progress of the entire project have been scheduled, but it is assumed that individual projects will be reviewed on a more frequent basis.

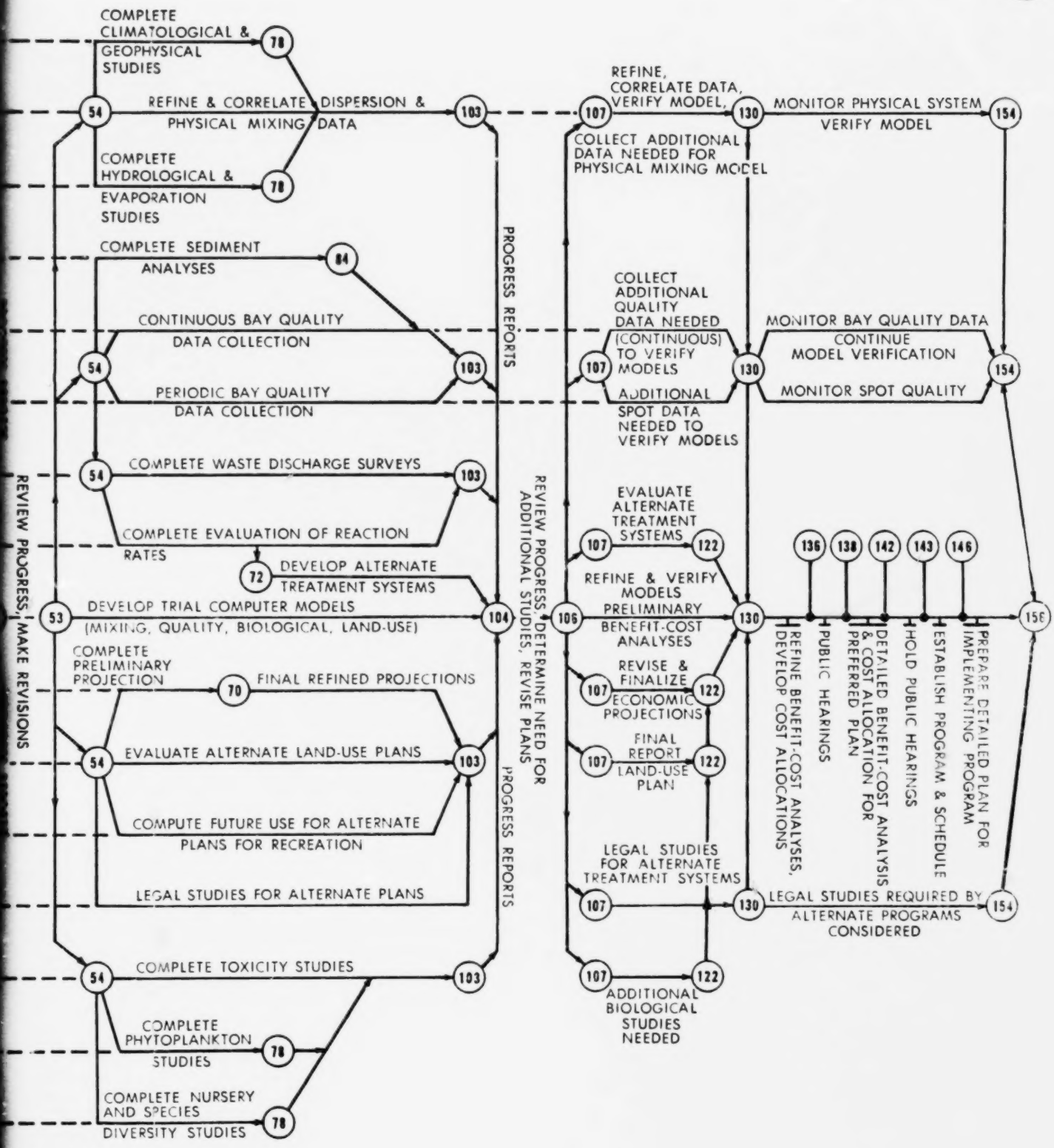
More nearly complete description of the individual projects are available in THE PLAN, and financial requirements of all projects are listed in THE BUDGET.

A



THE SCHEDU

NUMBERS IN CIRCLES INDICAT WEEK AFTER S



HE SCHEDULE

RCLES INDICA[T] WEEK AFTER START OF PROJECT